Node Based Adaptive Sampling and Advanced AUV Capabilities

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LONG-TERM GOAL

The general objective is to investigate basic and applied problems associated with the efficacious reconnaissance of littoral waters in support of mine warfare and oceanographic tasks.

OBJECTIVES

The main objective is to develop and refine node based adaptive sampling and hovering technology using FAU Morpheus vehicle as a test platform. The former one is a docking node where the vehicle can dock for power recharge and data upload. In adverse weather conditions, the autonomous docking and recharge capability allows for extended mission durations and also periodic sampling over days and possibly weeks. The adaptive part is enabled in two ways. In one the AUV sampling pattern is a function of the measured variables such as a gradient in temperature and turbulence. In the other human supervisors can generate pre-planned missions based on the results from prior days sampling and download them to the AUV while it is being docked and recharged. One significant issue is turnaround time for the AUVs for battery re-charge. Whereas the latter technology provides new interesting operational modes relevant to target surveys for inspection, identification and marking missions.

APPROACH

Docking

The docking payload is a flooded module that holds the “docking stinger”. The stinger is a fiber reinforced plastic shaft that hangs below the vehicle with a “docking puck” attached to the end. The connection between the vehicle and the stinger is a damping system that helps lessen the shock when the vehicle impacts the dock. The damping system is a rubber cylinder that is held inside a rigid cylindrical mount attached to the vehicle. The stinger shaft then runs through the center of the rubber cylinder. The prototype of docking payload used a full module 12-inch module, but this length will be reduced in a future version.

The basic dock design consists of a pyramid base with a guide above the intersection of each of the sides. The capture point of the dock is located at the top of the pyramid. This configuration is designed so that the vehicle has the option to dock from four different directions. This is so that the

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14. ABSTRACT

The general objective is to investigate basic and applied problems associated with the efficacious reconnaissance of littoral waters in support of mine warfare and oceanographic tasks.

15. SUBJECT TERMS

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approach direction can be at least somewhat into any existing current and thus reduce the impact speed without altering the water speed (under a certain water speed the vehicle will become less responsive to control inputs).

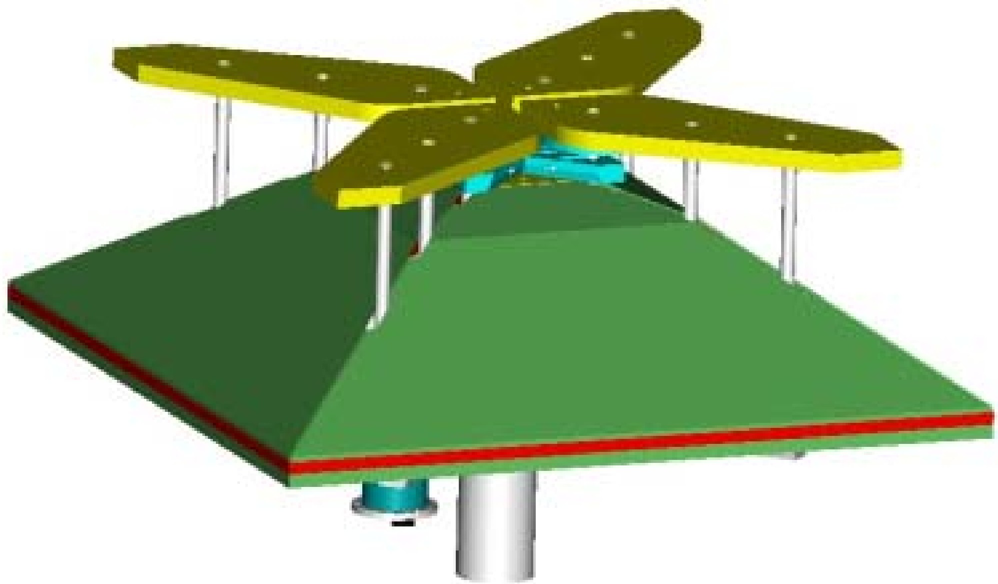


Figure 1. FAU Dock. Each side had a vertical ramp and two horizontal guides to guide the stinger into a capture point at top center of the dock.

If the vehicle approaches the dock below the capture point, the sides of the pyramid are designed to guide the puck at the end of the stinger up. If the vehicle approach is off to either side, the guides are designed to horizontally funnel the stinger shaft to the capture point. The resulting “window” that is created by this configuration which the vehicle must navigate to is about 12.5 inches vertically and 25 inches horizontally.

Once captured, the dock will charge the vehicle’s batteries and download and upload data. The vehicle can then remain at the dock until it’s next mission, at which time the horizontal guides move away from the center of the dock and allow the vehicle to float up from the dock.

Hovering

We propose to use a control framework that addresses all the degrees of freedom simultaneously. Specifically, an adaptive, self-tuning control framework is proposed, where the gains of a PID controller are updated in real time and adjusted according the dynamic response of the vehicle. By using such a control framework we avoid manually tuning the gains and we solve in this way the complexities associated with highly reconfigurable vehicles, complicated dynamics induced by side-thruster configuration, parameter uncertainties, and external disturbances.

WORK COMPLETED

A series of docking tests was performed which included two days of testing with a “dummy” vehicle followed by two days of testing with the real Morpheus. The initial tests were done with the dummy vehicle because the Morpheus was unavailable for docking experiments at the time. These tests were conducted in order to get a better sense of potential problems with the docking system. Additionally, the testing procedure could be refined to some degree. This would help minimize the time necessary to conduct tests with the Morpheus when it became available.

The dummy vehicle was constructed from empty Morpheus modules with weight placed inside each at a calculated position. This was done in order to get the weight and the center of gravity of the dummy vehicle as close as possible to that of the real vehicle.

Because the dummy vehicle did not have thrust or control, a spring loaded launching system was built that would propel the dummy vehicle off a guide pole and into the dock. The launcher and dock were mounted on the sea floor and the testing was conducted with divers.

The results of the tests with the dummy vehicle showed a fairly low success rate. A low percentage of the run ended with the stinger parting (or coming close to parting) the gates at the capture point and in many of those runs that were considered successful, the initial impact point was not far from the capture point. The primary mode of failure was due to the dummy vehicle loosing momentum before reaching the capture point. In some cases this occurred because the stinger, instead of impacting and then riding the ramp or guide to the capture point, would bounce back and forth several times between guides, before reaching the capture point. In other cases, because of the vehicle’s low roll moment and small center of buoyancy - center of gravity separation, the impact with the dock could cause a large roll and cause the stinger shaft to jam in the entrance to the capture point and fully stop the vehicle. From these tests it was concluded that for the docking system to have a chance of working the vehicle must provide thrust until it reaches the capture point. It was also concluded that the gates at the entrance to the capture point must be redesigned. Their design allowed any imperfection or marine growth to cause them to be very difficult to open.

Once the Morpheus became available, it was used for two more days of testing. The dock was again set up on the sea floor, but this time the vehicle approached the dock under it’s own power. The vehicle was started from a point that was located 10 meters from the dock. This distance was calculated to be enough to allow the vehicle to accelerate to about two knots before hitting the dock. For these tests, two divers were used to start the vehicle, follow it to the dock, and take it back to the start point for the next run. An additional two divers were armed with underwater video cameras to record the vehicle’s reaction when it impacted the dock.

For these tests the dock’s gates were removed. The original gates had been fouled from marine growth when the dock was awaiting recovery from the sea floor. Even after cleaning the gates, because of the design, they were nearly inoperable. It was assumed that a gate could be designed that would offer little resistance to the stinger as it entered the capture point and therefore not having the gates on the dock for theses tests would still produce valid results.

On the first day of testing with the Morpheus, the vehicle was commanded to run at a set altitude with a fixed water speed and heading. From the start point the vehicle was aimed at the dock before starting the thruster. The set altitude turned out to be too high for the first dive and then over corrected too low

for the second dive. This resulted in the vehicle having to be slightly guided into the dock by the divers.

In all, 30 runs were completed and the stinger hit within the docking window 15 times. Of the 15 times the vehicle hit within the docking window, the stinger went into the channel to the capture point, for what would be considered a successful dock, 13 times (87%). The initial impact locations had a fairly good distribution on the right side of the dock. Since the dock is symmetrical, the side that the vehicle impacted should not make much difference.

The same initial vehicle reaction that was observed in the testing done with the dummy vehicle and caused the vehicle to loose momentum also occurred with the real vehicle. With the real vehicle however, the constant force provided by the thruster was able to re-accelerate the vehicle, once it righted itself from any impact induced roll, and the vehicle would move to the capture point.

Because the divers were required to help guide the vehicle to the altitude of the dock, it was decided to run another day of tests and get the altitude setting correct. This was done by having several missions available for the divers in order to select with different altitude settings. The dock was also raised about 1.5 meters higher off the bottom because in the first day of testing with the Morpheus the doppler velocity log (DVL) was not far enough from the bottom for vehicle to record speed and position data.

On the second day of testing with the Morpheus, the altitude was adjusted to the correct setting and the divers did not interfere with the vehicle's flight to the dock. The stinger hit within the docking window 21 times of 39 runs overall. All of the runs where the stinger hit within the docking window either went in the channel to the capture point or appeared as if they would of without extenuating circumstances (a few cases where either the stinger constrains or stinger shaft broke or where the thruster shut off prematurely.

RESULTS

The results from the docking tests showed that the dock has a good chance of being a viable design for use with the Morpheus. With the vehicle under power and when the stinger hits the dock within the docking window, the rate of what were considered successful docks was 94% (34 of 36). When implemented with a docking controller on the vehicle that is capable of bringing the vehicle around for another attempt at docking if it misses the dock, this system should be adequately reliable.

There is a small chance of damage to the vehicle's control surfaces (mainly the stern planes) or the propeller if the vehicle slightly misses the dock. There is only a very small area that the vehicle would have to fly through that would allow the propeller to come into contact with dock. The rudders are fairly protected because one is on top of the vehicle and the other is behind the stinger. The stern planes probably have the highest risk of damage, however, in order for there to be enough energy to damage them it would probably take a case where the fin was the first point on the vehicle to hit the dock.

The implementation of a shroud around the thruster will alleviate the risk of damage to the propeller. To keep the fins from being damaged, a protective guard could be mounted in front of the stern planes or the fins could be made from a material that would absorb some of the energy of the impact.

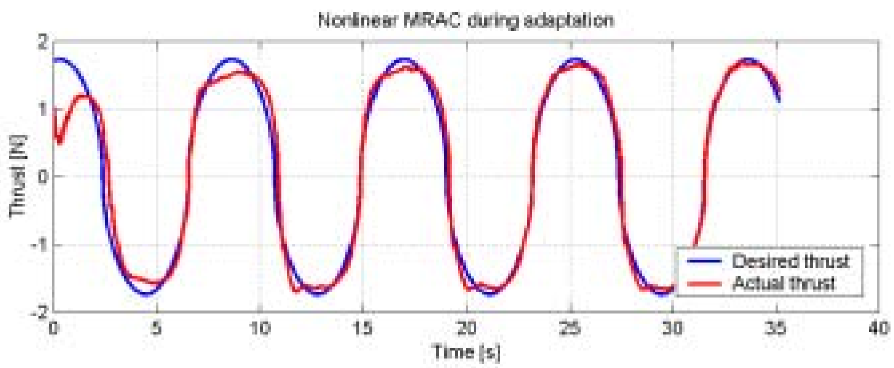
Gate Redesign

The original gates installed on the dock had a flaw in the design which allowed the friction force countering the opening force to have the potential of becoming very large. The gates were designed to slide open in a direction perpendicular to the motion of the stinger motion. This caused the normal force to be relatively large and if the coefficient of friction of the sliding mechanism did not remain small, the friction force would be large.

The new gate design uses a wedge shaped gate that rotates to move out of the way as the stinger shaft moves past. The guides were made thicker and a pocket was machined out near the channel for the gates. A compression spring was fixed behind the gate to cause the gate to spring back behind the stinger after it passed and lock it into the capture point.

The new gates were built and installed on the dock. Tests of the new gates with the vehicle in the water have not yet been completed. From testing in the lab by pushing the stinger in by hand however, the gates appear to work very well.

As for the hovering results, the adaptive control framework was successfully applied for the implementation of the low-level thrust control on the SQUID-AUV. The performance of the controller has been verified by mounting the vehicle in the wave tank available in the Hydrodynamics Laboratory at FAU and using a force sensor to measure the generated thrust. The dynamic relationship between the voltage input to the brushless DC motor the drives the propeller and the thrust generated is extremely complicated, mainly due to the unsteady hydrodynamics effects. Such dynamics need not to be known or modeled when using the described adaptive control framework, and good tracking results can be achieved despite of the poor knowledge of the system behavior and the effect of external generated in the tank.



IMPACT/APPLICATION

The node-based adaptive sampling and hovering technology will greatly enhance the clandestine operations for MCM with long endurance and inspection and identification capabilities.

TRANSITIONS

None

RELATED PROJECTS

1. Very Shallow Water Mine Reconnaissance with Multiple AUVs
2. Multiple Vehicle Sampling and Survey for MCM
3. Sampling and Survey with AUVs in Adverse Weather Conditions

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